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TRACKING RADAR TECHNIQUES FOR STUDYING MIGRATORY BIRDS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
Wallops Island, Va. 23337

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INTRODUCTION

Since March 1969, NASA tracking radars at Wallops Island, Virginia and on the islands of Bermuda and Antigua have been used to plot the paths of migratory birds in three dimensional space and to obtain data on the direction, speed and density of large numbers of migrating birds. This paper has been prepared in an effort to standardize the procedures at different radars, to assist personnel at other sites in using tracking radars for observation of migratory birds, and to inform biologists interpreting this data of the exact methods used for acquiring and following bird targets.

EQUIPMENT

The tracking radars used by this program are the following:

Radar	Peak Power	Beam Width	Maximum Usable Range for Birds
SPANDAR	5 MWatt	0.39°	100 km
FPQ-6	3 MWatt	0.4°	75 km
FPS-16	1 MWatt	1.2°	45 km
MPS-19	400 KWatt	2.8°	25 km

More information on the specifications of these radars is available from the NASA Wallops Station. We have also used the FPQ-6 and the FPS-16 at Bermuda and the FPQ-6 at Antigua. With regard to bird tracking these units appear to be similar to the radars at Wallops Island and will not be discussed separately, except to note that the cooled parametric amplifiers of the FPQ-6 at Antigua extend the range of this radar to about 90 km for birds.

For all the radars we have used the minimum useful range for birds is about 1500 meters. We had hoped that the lower powered MPS-19 would allow us to track birds closer to the radar, but the relatively broad beam width and numerous sidelobes increased the ground return greatly at short range and, thus, the shorter recovery time of the receiver could not be utilized.

Figure 1 illustrates the data outputs we obtain from tracking radars.

PPI Console

A Plan Position Indicator (PPI) console is installed in addition to standard tracking radar equipment to enable us to determine the approximate number, direction, speed and altitude of migrating birds. Because of its capability for continuously variable radius, for off-centering of

the origin, and its agile cursors, we find the UPA-35 console to be well suited for our work. The units are connected to the radar as shown in Figure 1. The PPI units may be used as Range Height Indicator (RHI) displays by feeding elevation rather than azimuth data to the PPI sweep, off-centering the origin to the edge of the PPI display, and operating the display at 18.5 km (10 n mi) range. The PPI console with a light-proof hood is monitored by a 10 x 12.7 cm (4 x 5 inch) format camera with a Polaroid film back and 3000 ASA speed film. Figure 2 shows two representative photographs from the PPI and RHI displays at SPANDAR, Wallops Island, Virginia.

Individual PPI displays may vary greatly in video intensity. We find it best to set the video gain at about 10% below saturation, somewhat brighter than would be used for visual detection of aircraft, and use an aperture of f8 or f11 for 4 minute exposure on ASA 3000 film.

Radar Signatures

One advantage of tracking radars over search radars is the possibility of identifying the target from its radar signature. Figure 1 shows two radar signature outputs. Radar signature #1 utilizing a peak detector circuit is necessary to discriminate high frequency signature components in non-monopulse radars. This output is not needed in monopulse radars in which the Automatic Gain Control (AGC) gives good frequency response directly. Radar signature #2 is obtained from all radars and consists of a paper chart record of the AGC and the azimuth and elevation error voltages. These give, respectively, a measure of the changes in radar cross-section with time and the horizontal and vertical extent of the target.

Real Time Plots

A 91 x 91 cm (three foot square) analog plot board is used to obtain real-time data on the position and altitude of the bird. Scales used are usually x=y = 1200 m/cm (x=y = 10,000 feet/inch), z = 48 m/cm (z = 400 feet/inch) and x=y = 2400 m/cm (x=y = 20,000 feet/inch), and z = 240 m/cm (z = 2,000 feet/inch).

Magnetic Tapes

Elevation, azimuth, range, and AGC level were recorded on tape once per second for all tracks.

Data Reduction

Primary data reduction was performed for all tracks longer than 5 minutes and consisted of a computer printout, at ten second intervals, of the x-y coordinates, altitude corrected for curvature of the earth, horizontal speed, and direction of flight and the rate of change in altitude. For each track we obtain a plot of the x-y position of the target, altitude vs. time and horizontal velocity vs. time.

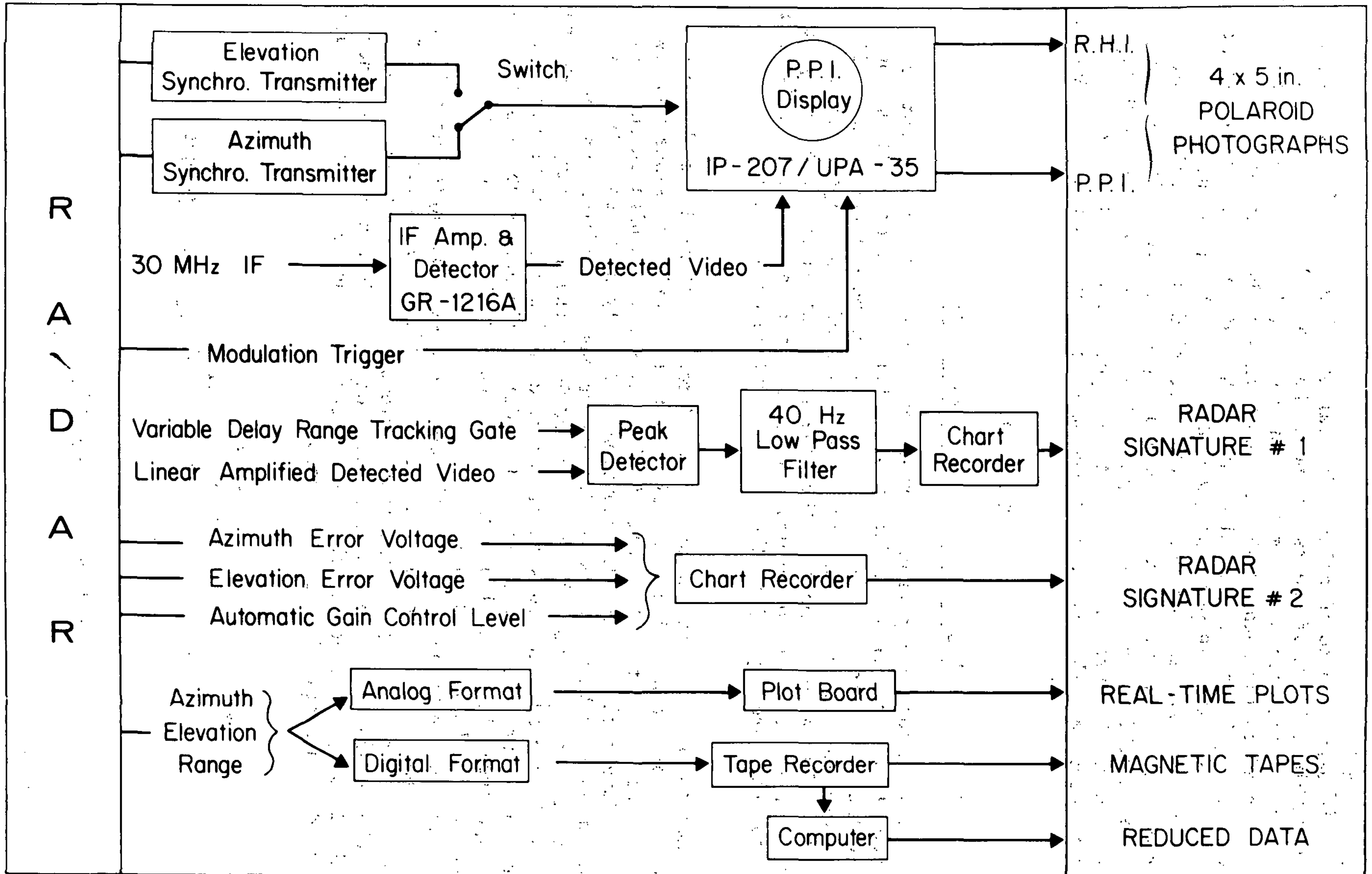


Figure 1. Data flow chart for tracking radar studies of bird migration.

Optical Tracking

It is desirable to identify radar targets visually. If the target passes within 2,000 m of the radar under the proper light conditions, birds can be seen with a 100 cm (40") or 200 cm (80") focal length telephoto camera slaved to the radar dish. Although this is best accomplished with the optical equipment mounted directly on the antenna, a camera mount at the base of the SPANDAR pedestal about 45 m from the antenna, has been used successfully. Data is most conveniently recorded on 16 mm color film at 24 frames per sec., but 35 mm film or still pictures have also been useful. Positive identification of the target is best accomplished by an observer sighting directly through the large telescope, but a spotting telescope (20") mounted near the camera lens has been used successfully at SPANDAR.

OPERATIONS

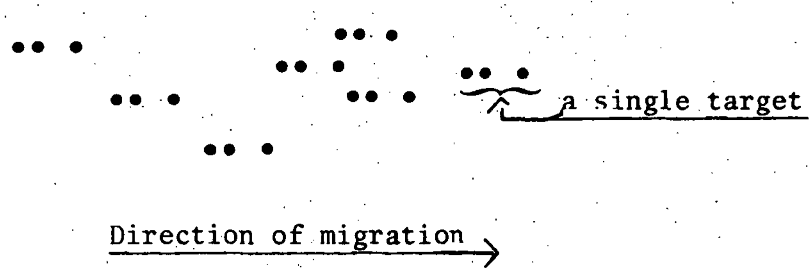
Phase 1: Survey of Birds Aloft

Before actually beginning to track bird targets we obtain data on the density distribution and direction of flight of birds aloft and on the weather conditions. These data serve two purposes; first, they allow us to determine the best areas for acquisition of bird targets; and, secondly, they give a sample of the general migration trends on any given night. This allows us to determine whether the relatively few birds we are able to track are typical of the overall pattern of migration.

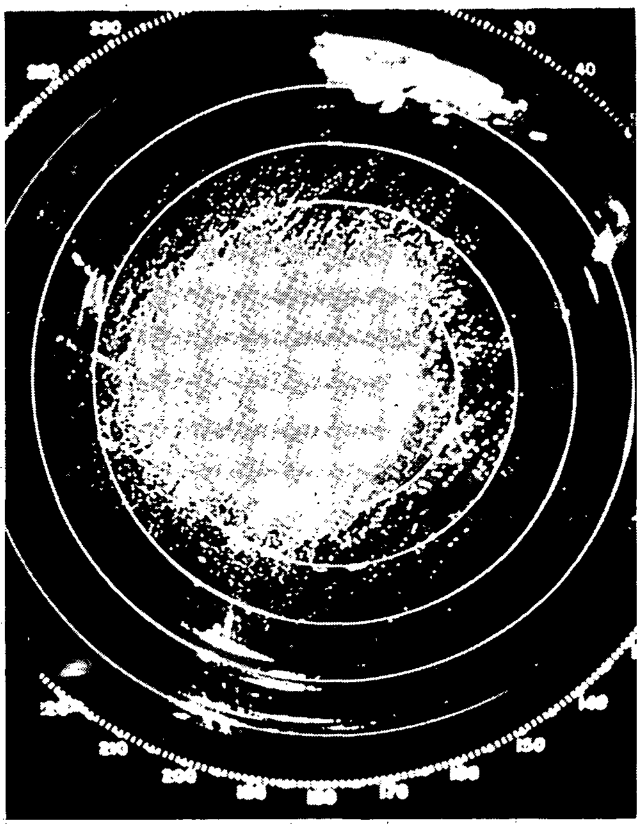
PPI

Horizontal distribution and flight direction of birds is obtained with PPI photographs. The angle of elevation is critical since too low an angle will fail to detect high flying birds but too high an angle will fail to detect the density distribution of low flying birds. The best solution is to take two or more PPI photographs at different angles of elevation. We find that 2° elevation and 90 km (50 n mi) range on the PPI display is a good standard setting for birds below 3000 meters altitude A second PPI at 5° elevation is used to detect migrations above 3000 meters. Although such high migrations are rare at Wallops Island, they occur frequently at Bermuda and Antigua.

The radar antenna is set at the desired elevation angle and allowed to rotate at about 1 RPM for four revolutions. The camera shutter is left open for two revolutions of the radar, closed for one revolution, and then opened again for the fourth revolution. The Polaroid film is then examined for bird targets. The bird tracks will show up as two small dots followed by a single dot as shown below:



a



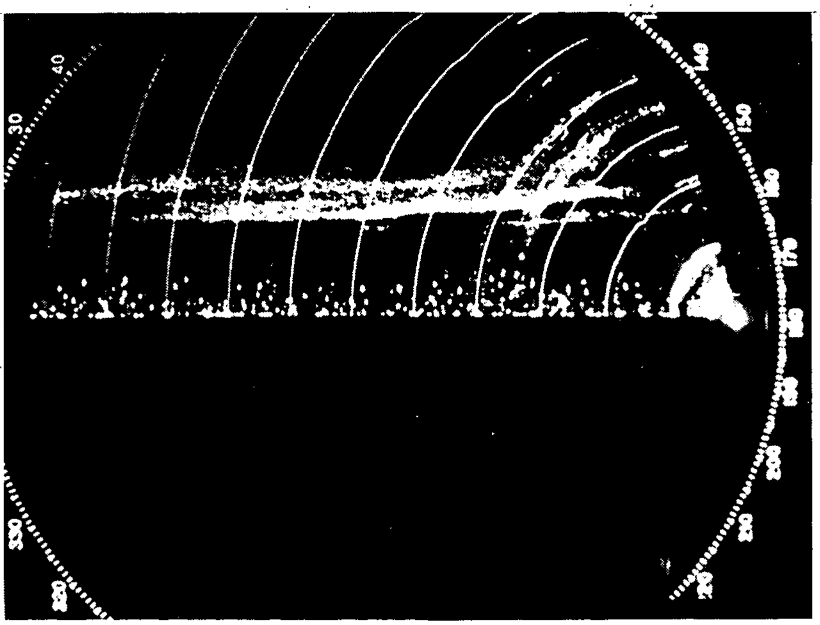
PPI Display

Moderate migration toward NNE (North is at the top).

Total Range: 92.5 km
Range Mark Interval: 18.5 km
Elevation Angle: 2°

Figure 2. SPANDAR displays for April 2, 1971.

b



RHI Display

Range Mark Interval: 3.70 km
Max. Alt. of Bird: 2.7 km
Alt. of Clouds: 7.6 km

Aircraft will appear as much larger dots spaced further apart. The Polaroid photographs are analyzed to determine the direction, speed and geographical location of primary migratory bird movements.

RHI

Altitude data on bird targets can be obtained in two ways. PPI photographs may be used by computing altitude from range of the bird targets and angle of elevation of the radar beam. RHI displays (see above under equipment) give information on the distribution of targets independently of range. The radar is directed at a desired azimuth and raised from 0° to 80°. The polaroid camera shutter is left open for only a single sweep of the radar beam. A sample RHI photograph is shown in Figure 2.

The RHI and PPI photographs represent the baseline data for each tracking period. Both types of photographs are taken as soon as possible on each day of operations, at about 2 hr. intervals during the tracking period, and are then repeated at the end of the tracking period.

High Density Bird Migration Procedures

In cases of extremely dense bird migration, the resolution of the PPI display may be increased by working at a 18.5 km (10 n mi) radius. For a determination of the density of migration the PPI is set at 18.5 km (10 n mi) and the radar rotated for 1 revolution at about 3° elevation (elevation is determined by the altitude of bird migration on a particular night). An off-center sector scale using either one or four revolutions has been used to investigate detailed movements over a small geographical area at ranges greater than 18.5 km from the radar.

Phase II: Acquisition of the Bird Target

The PPI and RHI photographs obtained under the survey phase above are analyzed to determine the general pattern of bird migration. We then decide which aspect of this migration we wish to study and what geographical area and altitude will be best for our observations. The radar operator is then given the following information:

Range ± 10 kilometers
Azimuth ± 20°
Antenna elevation ±1°

The radar operator then searches manually in the prescribed area for a bird target. At first the operator may have difficulty distinguishing between bird targets, clouds and aircraft. We have found the following characteristics helpful in making this discrimination:

In the display of echo amplitude vs. time (A scope) birds will appear as small targets (less than 45 db above noise at more than 20 km range). Bird targets also have a characteristic fluctuation which may be easily seen on the most expanded of the three A scope presentations which we use. This, of course, is due to the radar signature of the target; the echo will fluctuate at about 5 to 20 times per second. Echoes from clouds

tend to be poorly defined as opposed to bird echoes which are usually clearly defined targets.

Once the operator has selected a target he sets the radar to automatically track the target. Before we record data on the target we check its ground speed and direction to exclude possible tracks of aircraft. This is first done by the operator. Rates of change of azimuth should be relatively slow and somewhat uneven in contrast to aircraft which show a rapid and steady change in azimuth. Change in range rate is also used to exclude targets moving at more than 160 km/hr. Final checks on altitude, speed and heading are made with the analog plot board mentioned above.

In some situations the strip chart record of peak detector circuit output or AGC, as shown by Figure 1, may be helpful in recognizing bird targets. In general, though, these will be useful only if a single bird, rather than a flock, is present within a pulse volume. Figure 3 shows typical signatures for single birds. The signature for a flock of birds will look very much like noise. Once we have determined that the bird target is large enough to track and not be lost in clutter, the magnetic tape is started and we begin keeping a log of the track.

In acquiring bird targets it is wise to avoid low angles of elevation (less than 30'). Anomalous propagation of the radar beam may often cause any echoes for objects on the ground or inaccurate altitude data at low angles.

If the PPI display indicates a very heavy migration, that is if the photograph shows an almost solid return out to 50 or 75 km, acquisition of targets may be more difficult. Birds may be so numerous that the radar jumps from one target to another. In such cases we have had best results by using relatively great angles of elevation, between 3° and 6°, and choosing the more distant targets from the radar. These targets are often at about 15 to 50 km range and are well separated from each other. (See discussion of introduced bias in sampling below.)

Direct Use of the PPI for Target Acquisition

During normal and heavy migration the procedure outlined above is adequate for acquiring targets. It is, however, limited since the radar operator can scan only a relatively small area in range and azimuth. When the radar detects numerous echoes from clouds, or when relatively few birds are migrating, a second observer at the PPI console can greatly aid the radar operator. In this operation the PPI is set at about 50 km (30 n mi) range and the radar is swept back and forth over an area of 90°-180° at varying elevations. The observer at the PPI looks for small, clearly defined targets. Aircraft appear as very large clearly defined targets on the PPI and weather appears as poorly defined targets often extending over a large area. The observer at the PPI informs the radar operator of the exact range, azimuth and elevation of suspected bird targets. The operator then searches that area for bird targets as described above. The UPA-35 PPI display is fitted with an azimuth and range strobe by means of which a small dot of light on the PPI display

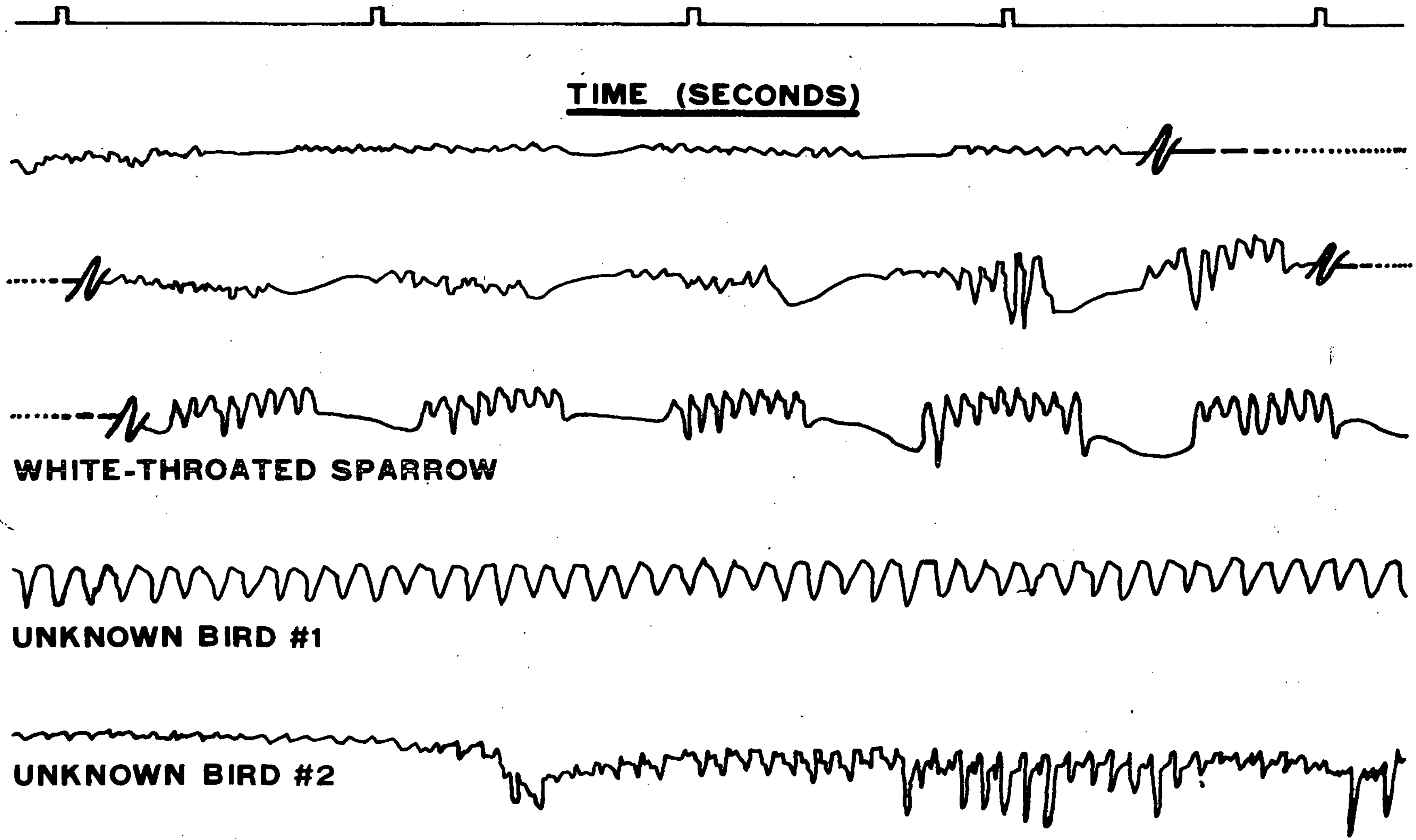


Figure 3. AGC records of birds (FPS-16 radar).

may be positioned over the presumed bird target. The azimuth and range of that target may then be read from the controls of the display. We have found this to be of great help at the SPANDAR site.

Phase III: Tracking

The survey and acquisition phases are aimed at selecting a target that will yield good data for tracking. The final phase seeks to optimize the data obtained. In tracking migrating birds there is a constant danger of losing the small targets or of switching to another target, particularly during times of heavy migration. The movements of the target are constantly monitored on the analog plot-board. The plot-board operator immediately informs the radar operator of any abrupt change in course or altitude. If the target is lost or if the radar switches to another nearby target, the plot-board operator assists the radar operator in reacquiring the original target. The plot-board operator extrapolates the course of the original target and can often verbally instruct the radar operator to search at a new range, azimuth and elevation. This technique is successful only during light and moderate levels of migration density. During heavy migrations we usually cannot be sure of picking up the same target. Once a target is reacquired the plot-board operator checks x-y and altitude plots for continuity with the previous target. (Further checks are made from the computer reduced data. We compare radar cross-section, horizontal and vertical speeds and headings. If any of these differ significantly, we assume that we failed to reacquire the original target.) Radar signature records are obtained every 20 minutes of tracking and also at any time that the plot-board operator suspects a switch in targets.

A continuous log of all operations is taken by an observer located near the radar operator. The log notes the exact time at which more than one target is seen in the tracking gate of the A scope, whether this was a target entering from outside the gate or a division of the primary target, and the presence of returns from weather near the target being tracked. The log also contains the times at which targets were acquired and dropped, and start and stop times of the magnetic tape and the function recorders. A weather check every 20 min. is also taken, including temperature, wind direction and speed, percent cloud cover, visibility of the moon, and presence of rain. It is difficult to overemphasize the importance of a carefully taken log. It is used for starting and stopping computer runs of the digital data and for correcting errors in this data as well as in the interpretation of conflicting data from different sources.

Discussion

Bird migration is, to say the least, a discontinuous phenomenon. Even during the migration season at Wallops Station we have ranged from periods in which we detected only 1 or 2 targets in a single PPI photograph of 150 km radius, to nights during which we counted over 1500

separate targets in a single 18.5 km radius PPI photograph. The tracking radar allows us to follow a few of the many targets with considerable precision, but the PPI display is needed to compare these tracks to the average behavior of large numbers of birds.

The performance of the tracking radars varies considerably with the density of bird migration. At light to moderate levels of migration it is possible to obtain tracks of a variety of types of targets, both large and small. During heavy periods of migration the sky is so filled with targets that only the largest targets can be tracked for more than a few minutes. Thus, there is undoubtedly a bias in our data toward larger targets, especially during nights of heavy migration. This bias becomes unimportant at sites such as Bermuda where the migration does not reach the density experienced on the mainland, or when we are tracking large targets such as waterfowl at any site. During the very dense movements of song birds over Wallops Island, it is possible to identify and analyze individual targets with the PPI display, but the birds appear to be so closely spaced that we switch targets every few minutes when trying to track under these conditions. There is also a bias against birds flying less than 200 m above ground. Such targets are rapidly lost in ground returns; since, these tracking radars lack MTI circuitry. Thus, the long range tracking radars appear to be best suited for tracking relatively large targets at relatively high altitudes. For this work they provide data unequalled by any other instruments. As targets get smaller, more numerous, and lower, the radar becomes somewhat less effective in maintaining contact with single targets; and, the data is less reliable due to anomalous propagation of the radar beam.